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PATENT APPLICATION

" THERMAL SWITCH CONTAINING PRE-FLIGHT TEST FEATURE AND FAULT LOCATION DETECTION "

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THERMAL SWITCH CONTAINING PREFLIGHT TEST FEATURE AND FAULT LOCATION DETECTION

This application claims the benefit of U.S. Provisional Application Serial No. 60/237,847, filed in the names of George D. Davis and Byron G. Scott on October 4, 2000, the complete disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention is directed to temperature sensors and, more particularly, to snap-action thermal switches and resistance thermal sensors.

BACKGROUND OF THE INVENTION

Snap-action thermal switches are utilized in a number of applications, such as temperature control and overheat detection of mechanical devices such as motors and bearings. In some applications, multiple thermal switches are located at different positions around the equipment. For example, in some aircraft wing, fuselage, and cowling overheat detection applications, multiple thermal switches located just behind the leading edge flap, while other thermal switches are spaced along the length of each wing. Additional thermal switches are located in the engine pylon and where the wing attaches to the fuselage. In this example, the multiple thermal switches are connected electrically in parallel, such that just two wires are used to interface between all of the switches on each wing and an instrument that monitors the temperature of the aircraft's wing, fuselage, and cowling.

Current snap-action thermal switch designs typically provide open and closed functions only. Typically, all of the thermal switches in the aircraft wing, fuselage, and cowling overheat detection applications are operated in the normally open state. The thermal switches are thus all in the "open" state until an overheat condition is detected, at which time one or more of the switches change to the "closed" state, thereby

completing the circuit causing a "right wing," "left wing" or "fuselage" overheat indication to appear in the cockpit. The pilot then follows the appropriate procedure to reduce the overheat condition.

Current snap-action thermal switches used in parallel operation, multiple thermal switch overheat detection systems suffer from various drawbacks. The integrity of the wire harness between the cockpit and the wing tip cannot be assured because the circuit is always open under normal operating conditions. If a switch connector is not engaged or the wire harness contains a broken lead wire, a malfunction indication will not occur, but neither will the overheat detection system operate during an actual in-flight overheat condition. Furthermore, if an overheat condition does occur, current snap-action thermal switches are not equipped to provide information describing the exact location of the overheat. In both instances, flight safety is compromised, and later correction of the problem that caused the overheat condition is made more difficult because of the inability to pinpoint the overheat fault.

SUMMARY OF THE INVENTION

The present invention overcomes the limitations of the prior art by providing a device that provides a self-test function in combination with a thermal overheat detection function.

According to one embodiment of the invention, a snap-action thermal switch structured in a normally open configuration is combined with a resistance element integral with the snap-action thermal switch and coupled to an output thereof.

According to one embodiment of the invention, the resistance element and the snap-action thermal switch share one or more common terminals. For example, the snap-action thermal switch is structured having a pair of terminals being mutually electrically isolated when the snap-action thermal switch structured in the normally open configuration, and the integral resistance element is electrically coupled to provide an output on the pair of electrically isolated terminals. According to different

embodiments of the invention, the resistance element is mounted either internally or externally to the snap-action thermal switch.

According to another embodiment, the invention is embodied as a three-terminal, snap-action thermal switch having first, second and third electrical terminals mounted in a header, the first, second and third terminal being mutually spaced apart and electrically isolated; a fixed electrical contact being positioned on the first terminal; a movable electrical contact being positioned on the second terminal and being biased into electrical contact with the fixed electrical contact; a bi-metallic actuator being convertible as a function of temperature between a first state wherein an actuation portion is positioned to space the movable electrical contact away from the fixed electrical contact and a second state wherein the actuation portion is positioned to permit electrical contact between the movable electrical contact and the fixed electrical contact; and an electrically resistive element coupled between the third electrical terminal and one of the first and second electrical terminals.

The invention also provides methods of accomplishing the same. For example, the method of the invention includes structuring a pair of electrical contacts in a normally open configuration; electrically interconnecting an electrically resistive element with at least one of the pair of contacts; and detecting a minimum electrical resistance of the electrically resistive element.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

Figures 1 is a top plan view of the present invention embodied as a single-pole, single-throw snap-action thermal switch having an interiorly mounted resistor;

Figure 2 is a cross-sectional view of the snap-action thermal switch of the present invention embodied as shown in Figure 1 with the contacts open and showing the interiorly mounted resistor;

Figure 3 is a cross-sectional view of the snap-action thermal switch of the present invention embodied as shown in Figure 1 with the contacts closed and showing the interiorly mounted resistor;

Figure 4 is a schematic description of the single-pole, single-throw thermal switch shown in Figures 1 through 3;

Figure 5 is a top plan view of one alternative embodiment of the present invention embodied as a snap-action thermal switch having an externally mounted resistor;

Figure 6 is a side view of the snap-action thermal switch of the present invention embodied as shown in Figure 5;

Figure 7 is a top plan view of one alternative embodiment of the present invention embodied as a snap-action thermal switch having an externally mounted resistor, the thermal switch installed in an over-molded housing configured for mounting in an aircraft wing, fuselage, or cowling, as shown in Figure 17;

Figure 8 is a side view of the snap-action thermal switch of the present invention embodied as shown in Figure 7 and shows the externally mounted resistor;

Figure 9 is an illustration of the thermal switch of the invention implemented in an overheat detection system having one of the thermal switches coupled in parallel with a quantity of conventional snap-action thermal switches that do not include the resistor;

Figure 10 illustrates the thermal switch of the invention implemented in an alternative overheat detection system having a quantity of thermal switches of the invention coupled together in parallel in a wiring harness, which is led to an indicator through a logic circuit;

Figure 11 illustrates an alternative embodiment of the overheat detection system of the invention, wherein each of the multiple parallel-coupled thermal switches of the invention is embodied having respective resistor electrically coupled in parallel

with the switch contacts and wherein each of the resistors has a resistance value different from that of the other resistors coupled to the other switches;

Figure 12 illustrates an exemplary flow diagram of one optional embodiment of the logic circuit shown in Figure 11;

Figures 13A and 13B together illustrates the logic circuit embodied according to an alternative exemplary flow diagram, wherein the logic circuit includes the structure of the embodiment illustrated in Figure 11, but also includes a front-end portion that provides an initial state determination before attempting to isolate a fault;

Figure 14 illustrates the thermal switch of the invention embodied as a three-terminal switch;

Figure 15 is a cross-sectional view of the three-terminal thermal switch illustrated in Figure 14;

Figure 16 is a schematic description of the three-terminal thermal switch shown in Figures 14 and 15; and

Figure 17 illustrates the overheat detection system of the invention having the thermal switch of the invention as installed in an aircraft for supplying overheat detection in the wing, fuselage, and cowling.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

In the Figures, like numerals indicate like elements.

The present invention is a thermal protection device that provides a resistor in combination with a normally open, snap-action thermal switch until the switch changes state from open to closed. This resistor in combination with a normally open, snap-action thermal switch provides several advantages over typical thermal protection devices. For example, the resistor provides a means for determining if switch connector is not engaged, or the wire harness contains a broken lead wire. In these and like circumstances a malfunction indication will occur during pre-flight check or en route, if the failure occurs during flight. While the overheat detection system remains operational, a malfunction indication will occur during an actual in-flight overheat

condition. Furthermore, if an overheat condition does occur, the thermal switch of the present invention is equipped with the serial connected resistor to provide information describing an exact location of the overheat. Flight safety is thereby enhanced, and later correction of the problem that caused the overheat condition is simplified because of the ability to pinpoint the location of the overheat fault.

Figure 1 is a top plan view and Figure 2 is a cross-sectional view of the present invention embodied as a snap-action thermal switch 10 having an internally mounted resistor 12. The thermal switch 10 includes a pair of electrical contacts 14, 16 that are mounted on the ends of a pair of spaced-apart, electrically conductive terminal posts 20 and 22. The electrical contacts 14, 16 are moveable relative to one another between an open and a closed state under the control of a thermally-responsive actuator 18. According to one embodiment of the invention, the thermally-responsive actuator 18 is a well-known snap-action bi-metallic disc that inverts with a snap-action as a function of a predetermined temperature between two bi-stable oppositely concave and convex states. In a first state, the bi-metallic disc actuator 18 is convex relative to the relatively moveable electrical contacts 14, 16, whereby the electrical contacts 14, 16 are moved apart such that they form an open circuit. In a second state, the bi-metallic disc actuator 18 is concave relative to the relatively moveable electrical contacts 14, 16, whereby the electrical contacts 14, 16 are moved together such that they form an closed circuit.

As illustrated in Figures 1 and 2, the thermal switch 10 includes the two terminal posts 20, 22 mounted in a header 24 such that they are electrically isolated from the header 24 and from one anther. For example, the terminal posts 20, 22 are mounted in the header 24 using an electrical isolator 26 (shown in Figure 1) formed of an electrically isolating glass or epoxy material.

As shown in Figure 2, the contact 14 is fixed on the lower end of one terminal post 20. The contact 16 is moveable on the end of a carrier 28 in the form of an armature spring, which is fixed in a cantilever fashion to the lower end of the other terminal post 22. The electrical contacts 14, 16 thus provide an electrically conductive path between the terminal posts 20, 22. Upward pivoting of the armature spring 28

moves the movable contact 16 out of engagement with the fixed contact 14, whereby an open circuit is created. Downward pivoting of the armature spring 28 moves the movable contact 16 into engagement with the fixed contact 14, whereby the terminal posts 20, 22 are shorted and the circuit is closed.

The movable contact 16 is controlled by the disc actuator 18, which is spaced away from the header 24 by a spacer ring 30 interfitted with a peripheral groove 32. A cylindrical case 34 fits over the spacer ring 30, thereby enclosing the terminal posts 20, 22, the electrical contacts 14, 16, and the disc actuator 18. The case 34 includes a base 36 with a pair of annular steps or lands 38 and 40 around the interior thereof and spaced above the base. The lower edge of the spacer ring 30 abuts the upper case land 40. The peripheral edge of the disc actuator 18 is captured within an annular groove created between the lower end of the spacer ring 30 and the lower case land 38.

As shown in Figure 2, while the thermal switch 10 is maintained below a predetermined overheat temperature, the disc actuator 18 is maintained concave relationship to the electrical contacts 14, 16. The concave disc actuator 18 pivots the armature spring 28 upwardly to separate the contacts 14, 16 through the intermediary of a striker pin 42 fixed to the armature spring 28. Separation of the contacts 14 and 16 creates normally open circuit condition.

The resistor 12 is mounted to the interior of the thermal switch 10 and electrically connected to the two terminal posts 20, 22. For example, the resistor 12 is bonded to an inner surface of the header 24 using a bonding agent 44, such as an epoxy. Lead wires 46, 48 attached to the resistor 12 are electrically coupled to each of the terminal posts 20, 22. For example, the lead wires 46, 48 are spot welded to an outer surface of the corresponding terminal post 20, 22. The output of the internally mounted resistor 12 is available on the terminal posts 20, 22 while the electrical contacts 14, 16 provide an open circuit.

The thermal switch 10 is sealed to provide protection from physical damage. The thermal switch 10 is optionally hermetically sealed with a dry Nitrogen gas atmosphere having trace Helium gas to provide leak detection, thereby providing the

electrical contacts 14, 16 and the internal resistor 12 with a clean, safe operating environment.

Figure 3 illustrates the thermal switch 10 as a closed circuit, wherein the contacts 14, 16 are shorted. In response to a increase in the sensed ambient temperature above a predetermined set point, the disc actuator 18 inverts in a snap-action into a concave relationship with the electrical contacts 14, 16, the disc actuator 18 entering a space between the lower case land 38 and the case end 36. The lower end 50 of the striker pin 42 is normally spaced a distance from the actuator disc 18 so that slight movement of the actuator disc 18 will not effect contact engagement. The armature spring 28 is pivoted downwardly, which moves the movable contact 16 into engagement with the fixed contact 14, thereby creating a short and closing the circuit. The output of the internal resistor 12 is not available when the electrical contacts 14, 16 are shorted and the circuit is closed. As described in detail below, removal of the resistance of the internal resistor 12 identifies the particular switch that has responded to an overheat condition so that the location of the overheat event is identified.

Due to the nature of the snap-action disc actuator 18, the output of the internal resistor 12 becomes available again when the sensed ambient temperature is reduced below the predetermined set point and the disc actuator 18 returns to its convex state relative to the electrical contacts 14, 16, so that the resistance of the internal resistor 12 is again presented with an open circuit on the two terminal posts 20, 22.

Figure 4 is a schematic description of the single-pole, single-throw thermal switch 10 shown in Figures 1 through 3. As illustrated, the single-pole, single-throw thermal switch 10 is structured such that a resistance R12 is by-passed when the switch contacts 14, 16 are closed.

Figures 5 and 6 illustrate an alternate embodiment of the invention wherein the resistor 12 is installed on an exterior surface 52 of the thermal switch 10 and the lead wires 46, 48 are attached to exterior surfaces of the terminal posts 20, 22 of the thermal switch 10. The internal resistor 12 is, for example, bonded to the exterior surface 54 of the header 24, as shown in Figures 4 and 5.

Figure 7 is a top plan view of the thermal switch 10 of the present invention embodied as a snap-action thermal switch 10 having a resistor 12 coupled in parallel with the switch contacts 14, 16 (shown in Figures 2, 3) and installed in a housing 56 that is configured for mounting in an aircraft wing, fuselage, or cowling, as shown in Figure 17. Figure 8 is a break-away side view of the snap-action thermal switch 10 of the present invention embodied as shown in Figure 7. The housing 56 may include a threaded adapter member 58 for mounting, either in a threaded hole or through a clearance hole with a nut. An over-mold 60 is formed over and encases the thermal switch 10, the resistor 12 (shown mounted externally), the terminal posts 20, 22, and partially encases a pair of contact adapters 62, 64 that are electrically coupled to the terminal posts 20, 22, respectively. The contact adapters 62, 64 are internally threaded to enable the thermal switch 10 to be electrically coupled into the overheat detection system. The over-mold 60 is formed of an electrically insulative material, such as one of the conventional high-temperature thermo-plastic or thermo-set materials. The over-mold 60 may include an integral physical barrier portion 66 to protect against inadvertent contact between connectors (not shown) that are attached to the contact adapters 62, 64 for installing the switch 10 into the overheat detection system.

Figure 9 illustrates the thermal switch 10 of the invention implemented in an overheat detection system 100 having one of the thermal switches 10 coupled in parallel with a quantity of conventional snap-action thermal switches 102 that do not include the resistor 12. The single thermal switch 10 of the invention and the conventional thermal switches 102 are electrically coupled together in parallel by a wire harness 104, which is led to an indicator 106. In a conventional overheat detection system, the indicator 106 provides a visual and/or an aural indication of an overheat condition sensed by the overheat detection system. In other words, if one of the conventional thermal switches 102 responds to an overheat condition by closing its electrical contacts, whereby the circuit formed with the wire harness 104 is closed, the indicator 106 is connected to a voltage source V. The indicator 106 responds by either emitting an aural warning or displaying a visual warning of the overheat condition.

According to the embodiment of the overheat detection system 100 illustrated in Figure 9, the wiring harness 104 exhibits a nominal resistance R_N resulting from the electrical wire in the harness 104. The single thermal switch 10 is coupled into the overheat detection system 100 as the end switch. Thus, when the thermal switch 10 is on-line and in the intended normally-open state, the resistor 12 appears on the wiring harness 104 as a minimum resistance R_T in addition to the nominal resistance R_N. Thus, the thermal switch 10 is detected as being on-line when a system resistance $R_S = R_N + R_T$ is detected by a logic circuit 108. Detection of the thermal switch 10 ensures that the wiring harness 104 is intact and operational, even though the connections of the conventional thermal switches 102 are not indicated.

Figure 10 illustrates the thermal switch 10 of the invention implemented in an alternative overheat detection system 110 having a quantity of thermal switches 10a, 10b through 10n of the invention coupled together in parallel in the wiring harness 104, which is led to the indicator 106 through a logic circuit 112. The logic circuit 112 samples the total system resistance $R_S = R_N + R_{Ta} + R_{Tb} \ldots + R_{Tn}$ of the detection system 110 at a predetermined sampling rate, wherein R_N is the nominal resistance of the wiring harness 104 and R_{Ta} through R_{Tn} are the resistances of the resistors 12 of the respective thermal switches 10a through 10n.

As embodied in Figure 10, the indicator 106, as part of the overheat detection system 110 of the invention, additionally provides a fault indication when the resistance R_S of the system 110 detected by the logic circuit 112 fails to fall between a minimum and a maximum threshold resistance. The overheat detection system 110 employs a number of the thermal switches 10 of the invention, each including one of the resistors 12, that provide at least a minimum resistance R_S that is below the maximum threshold resistance only when all of the resistors 12a through 12n are coupled together in parallel. If the resistor 12 of one of the normally-open thermal switches 10 is removed from the system circuit, then the overall resistance of the system 110 is increased above the maximum threshold, and the indicator 106 indicates a fault. Thus, the thermal switch 10 of the invention having the resistor 12 coupled in parallel with the electrical contacts 14, 16 provides a means for determining that all of the thermal

switches 10 of the overheat detection system 110 are on-line. The thermal switch 10 of the invention further provides a means for confirming the integrity of the wire harness 104 by indicating a fault unless the resistance provided by the resistor 12 portion of each of the switches 10 appears on-line. If the electrical contacts 14, 16 one of the thermal switches 10 are closed, instead of being in the normally-open state, the system circuit is CLOSED and the system resistance R_S is reduced to the actual resistance in the interconnecting wires of the wiring harness 104, which is reduced below the minimum threshold resistance. Thus, in a self-test mode, a switch 10 that fails in the closed state results in a fault indication. Similarly, when a switch 10 of the invention closes in response to an overheat condition, a fault indication results on the indicator 106.

According to one embodiment of the invention, a quantity of the thermal switches 10a through 10n of the invention, each including a respective resistor 12a through 12n coupled in parallel with the electrical contacts 14, 16, are coupled to a pair of wire harnesses 104. The thermal switches 10a through 10n and a respective wire harness 104 are deployed on one of the left and right sides of an aircraft to detect overheat conditions in the respective aircraft wing, fuselage, and cowling, as shown in Figure 17.

Figure 11 illustrates the overheat detection system embodied as an alternative overheat detection system 120, wherein each of multiple parallel-coupled thermal switches10a, 10b, through 10n of the invention is embodied having respective resistor 12a, 12b, through 12n electrically coupled in parallel with the switch contacts 14, 16. Each of the resistors 12a through 12n has a resistance value different from that of the other resistors 12a through 12n. A logic circuit 122 is coupled in series with each of the parallel-coupled thermal switches10a through 10n for detecting a resistance R_S that is the combined resistances of all of the resistors 12a through 12n, plus the nominal resistance of the wiring harness 104. The logic circuit 122 is structured to detect whether the total system resistance R_S of the system 120 is between the minimum and a maximum threshold resistance, as described above. The logic circuit 122 is thus structured to detect whether the wiring harness 104 is intact and functional and whether all of the thermal switches10a through 10n are on-line.

The logic circuit 122 is further structured, by means known to those of ordinary skill, to detect the actual resistance R_S of the overheat detection system 120 and, when a failure is detected, to determine from the actual resistance R_S which of the multiple thermal switches10a through 10n is off-line or closed.

Figure 12 illustrates the logic circuit 122 embodied in an exemplary flow diagram, wherein the logic circuit 122 includes a series of widow comparitor circuits 124a through 124n each being structured to determine whether the resistor 12a through 12n of the respective thermal switches 10a through 10n is on-line, or is missing from the circuit. In other words, failure to detect one specific resistance value indicates that a particular resistor 12m is no longer part of the circuit resistance R_S, and that the respective switch 10m is off-line, *i.e.*, disconnected. For example, the value of the resistance R_S of the overheat detection system 120 is between predetermined minimum and maximum resistance couples R_{a1} and R_{a2} through R_{an-1} and R_{an}. Such a fault is optionally determined by applying a voltage V to the system 120 during a pre-flight self-test operation. If any of the thermal switches 10a through 10n is determined to be off-line, a respective fault signal 126a through 126n is generated and passed to the fault indicator 106, which indicates the fault in the cockpit. Constant sampling at a predetermined sampling rate during operation causes the logic circuit 122 to continue to monitor the circuit resistance R_S for presence on-line of the multiple thermal switches 10a through 10n.

Furthermore, the logic circuit 122 includes another series of widow comparitor circuits 128a through 128n each being structured to determine whether the resistors 12a through 12n of the respective thermal switches 10a through 10n are on-line, or whether one has been replaced by the minimal resistance of the closed switch contacts 14, 16 in series with the wire resistance of the parallel portion of the wiring harness 104, which indicates that the respective switch 10 has closed in response to an overheat situation. If any of the thermal switches 10a through 10n is determined to be closed, a fault signal 130a through 130n is generated and passed to the fault indicator 106, which indicates the fault in the cockpit. Constant sampling at a predetermined sampling rate during operation causes the logic circuit 122 to continue to monitor the

circuit resistance R_S for presence on-line of the multiple thermal switches 10a through 10n.

Figures 13A and 13B together illustrates the logic circuit 122 embodied according to an alternative exemplary flow diagram, wherein the logic circuit 122 includes the structure of the embodiment illustrated in Figure 11, but also includes a front-end portion that provides an initial state determination before attempting to isolate a fault. For example, the logic circuit 122 includes a first state determination window comparitor 132 for determining whether all of the switches 10a through 10n are on-line by, for example, determining whether the overall resistance R_S of the overheat detection system 120 is between the predetermined minimum and maximum resistance thresholds. Such a fault is optionally determined by applying a voltage V to the system 120 during a pre-flight self-test operation. If the overall resistance R_S is outside the minimum and maximum limits, the signal is passed through the respective window comparitors 124a through 124n to determine which of the thermal switches 10a through 10n is off-line and to generate the fault signal 126a through 126n that corresponds to the switch 10a through 10n that is off-line. As described above, the fault indicator 106 indicates the fault in the cockpit in response to the respective fault signal 126a through 126n received.

Figure 14 illustrates the thermal switch of the invention embodied as a three-terminal switch 140 having a third electrically conductive terminal post 142 using an electrical isolator 26. The third terminal post 142 is a contact-less post that is physically spaced-apart from each of the first pair of terminal posts 20 and 22. A second resistor 144 is mounted on the header and electrically coupled between the contact-less terminal post 142 and one of the first pair of terminal posts 20 and 22 (shown as coupled to post 22) by respective lead wires 146, 148.

Figure 15 is a cross-sectional view of the three-terminal thermal switch 140 shown in Figure 14.

Figure 16 is a schematic description of the three-terminal thermal switch 140 shown in Figures 14 and 15. As illustrated, the three-terminal thermal switch 140 is structured such that a resistance R144 is remains when the switch contacts 14, 16 are

closed. The switch 140 otherwise operates similarly to the above described thermal switch 10.

Figure 17 illustrates the overheat detection system 100, 110, 120 having the thermal switch 10, 140 of the invention as installed in an aircraft 150 for supplying overheat detection in the wing, fuselage, and cowling. The overheat detection system 100, 110, 120 includes the thermal switch 10, 140 installed in the wiring harness 104. As described above, the thermal switch 10, 140 is either used throughout the overheat detection system 100, 110, 120 or coupled in parallel with a quantity of conventional snap-action thermal switches 102. The overheat detection system 100, 110, 120 is operated as described above to perform a pre-flight self-test operation, to detect overheat situations, to generate and display an appropriate fault signal, and optionally to determine the specific thermal switch 10, 140 is responsible for the fault signal.

While the preferred embodiment of the invention has been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.